A Better Method for Certifying the Nuclear Stockpile

LAWRENCE Livermore and Los Alamos—the two national laboratories that designed the nuclear systems in U.S. nuclear weapons—are working together to develop an improved methodology for verifying the performance of these systems and for presenting those data in a common format. Known as quantification of margins and uncertainties (QMU), this methodology draws together the latest data from simulations, experiments, and theory to quantify confidence factors for the key potential failure modes in every weapon system in the stockpile.

The assertion that the nuclear explosive package in a weapon performs as specified is based on a design approach that provides an adequate margin against known potential failure modes. Weapons experts judge the adequacy of these margins using data from past nuclear experiments, ground and flight tests, and material compatibility evaluations during weapons development as well as routine stockpile surveillance, nonnuclear tests, and computer simulations.

"With QMU, we're still examining margins against potential failure modes," says Charles Verdon, who leads A Program in Livermore's Defense and Nuclear Technologies (DNT) Directorate. "But now the assessment of these margins relies much more heavily on surveillance and computer simulations than in the past and therefore must be more rigorous and quantifiable."

The Confidence Factor

A confidence factor for a component or system is defined as the performance margin divided by the uncertainty in evaluating that margin. For a nuclear weapon, if the confidence factor for each potentially significant failure mode is greater than or equal to 1, the overall system can be considered safe and reliable.

$$\text{Confidence factor, CF} = \frac{\text{Margin}}{\text{Uncertainties}}$$

If CF $\geq$ 1, then system is considered safe and reliable.

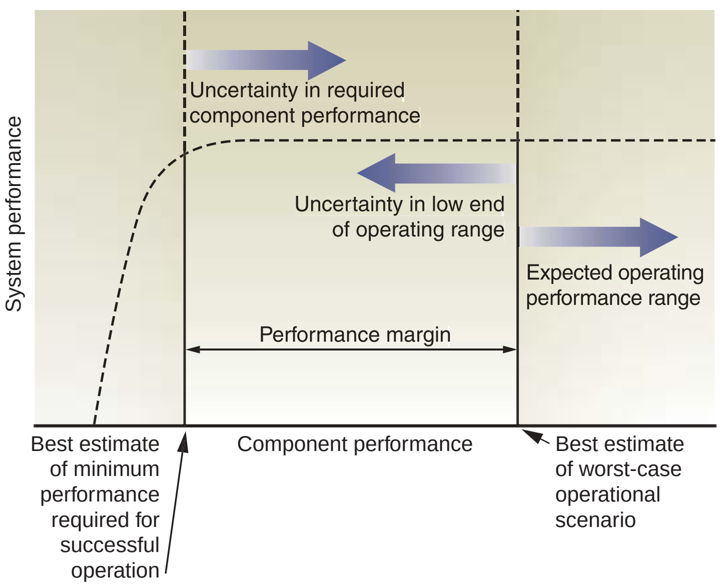
A nuclear warhead or bomb is designed to operate successfully at a performance level that is slightly lower than the level defined for the worst-case scenario of potential operating conditions. (See the figure on p. 20.) In defining the worst-case scenario, weapons experts consider numerous events that may occur during a weapon's lifetime, such as extremely cold atmospheric temperatures, vibration, or tritium decay between a gas-transfer-system exchange—any one of which could reduce weapon performance. The difference between these two levels—minimum required performance for successful operation versus the best estimate of the worst-case performance—constitutes the performance margin.

Many variables affect how a weapon will actually perform. Some of these variables, such as changes that alter the structural integrity of the weapon's outer casing or the behavior of plutonium as it ages, give rise to uncertainties about the best estimates of the minimum performance and the worst-case scenario for operation. Technical uncertainties are the root cause of such variables. For example, the equation of state for plutonium, which is arguably the most important material in the nuclear weapons stockpile, is not yet well understood when it is at the high-temperature and -pressure conditions that exist during a nuclear explosion. (See *S&TR*, January/February 2004, pp. 12–14.)

According to Kent Johnson, DNT chief of staff, reducing these technical uncertainties drives Livermore's continuing quest to understand the multitude of weapon constituents through experiments and simulations. "As our understanding increases, uncertainties may also increase for a while," he says, "but ultimately, we expect uncertainties to decrease considerably."

Today, no new nuclear weapons are being developed, and those in the current stockpile are being maintained beyond their originally planned lifetimes. To ensure the performance of these aging weapons, Livermore and Los Alamos take a survey–assess–refurbish approach to evaluating the stockpile. QMU, the methodology being used in the assessment part of this approach, helps weapon scientists identify where and when they must refurbish a weapon system. QMU is also proving useful for deciding whether the designed refurbishments are adequate.

Routine surveillance of stockpiled weapons has been a feature of weapon maintenance for decades, and it continues today. A more aggressive approach to surveillance under the National Nuclear Security Administration's (NNSA's) Stockpile Stewardship Program examines individual components to understand the aging process and its effects, if any, on overall performance. Nonnuclear tests at the Contained Firing Facility at Livermore's Site 300, at the Joint Actinide Shock Physics Experimental Facility at the Nevada Test Site, and soon at the National Ignition Facility at Livermore—all three of which were developed since nuclear testing ceased—are critical for scientists to better understand how materials behave during a nuclear explosion. In addition, Livermore's terascale supercomputer ASCI White, one of the largest in the world, provides the computing power needed for high-resolution simulations that incorporate most of the physical interactions that occur during a nuclear explosion.



An example of the relationship between the performance of a component and the overall nuclear weapon system. Uncertainties at both ends of the performance margin may reduce the margin. Numerical simulations, nonnuclear tests, data from past underground experiments, and the latest theory are combined to quantify technical uncertainties (the sum of the magnitude of the two uncertainty arrows) and the performance margin.

QMU pulls together all of this information—plus the latest physics theory and useful historic nuclear-test data—to arrive at quantifiable information with which decisions can be made about weapon certification or to answer questions about any weapon or weapon component in the stockpile. In 2001, QMU was successfully applied in the certification process for the W87 Alt342, the major refurbishment of the W87 nuclear weapon that was pursued through the warhead's life-extension program.

The goal is to fully integrate QMU into the nation's formal Annual Assessment of the entire stockpile of nuclear weapons. Each year, the directors of Livermore, Los Alamos, and Sandia national laboratories sign a letter to the President stating whether the weapon systems designed by each laboratory meet all safety, reliability, and performance requirements. By using QMU methodology, the laboratories will have a common framework for all of the necessary evaluations that comprise the Annual Assessment.

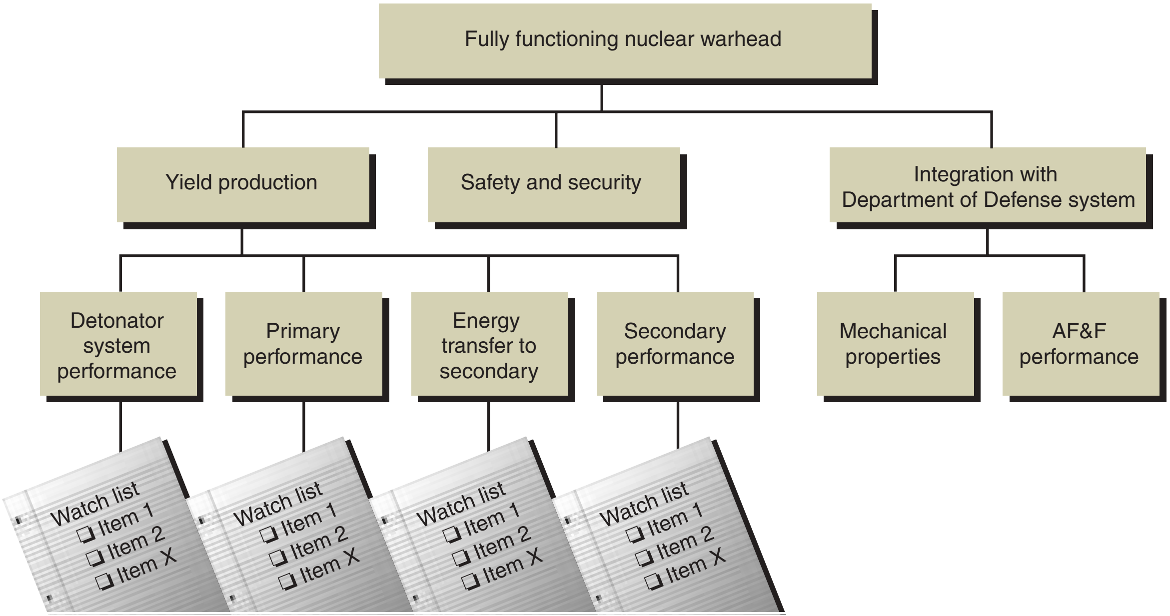
Making QMU Work

To implement the QMU process for a Livermore-designed weapon in the stockpile, weapon scientists first identify a set of components on which to focus in-depth analysis. Teams of experts define watch lists of credible failure modes and performance issues. For example, they are concerned with how current weapons will perform at extreme temperatures and whether component aging will affect performance. They also watch for such conditions as detonator deterioration and metal corrosion.

"The things on the list are the ones that keep us awake at night," says Verdon. "We want to know what parts might be approaching the edge of the performance margin, particularly if there are variables that could affect performance even more. Then we know that our scientists are working on the truly sensitive issues. During this continuing process, we must also stay vigilant for the unexpected."

For weapons that are being modified to prolong their life in the stockpile, new engineering features and proposed changes receive the same scrutiny. In these life-extension projects, scientists must determine quantitative answers to questions such as: Are the proposed changes a good idea? Does a modification fix the problem it was designed to solve? Does the modification introduce other problems?

Experts have developed a taxonomy of uncertainties for which scientists are always on the lookout. They are known, known-unknown, and unknown-unknown uncertainties. One example of a known uncertainty is the structural integrity of the weapon's casing. Engineering details are well known, but vibration during flight may crack the case and cause contents to be rearranged.



The first step in quantifying margins and uncertainties for a warhead or bomb designed by Livermore is to identify a watch list of potential failure modes and issues.

This known uncertainty can be accommodated through design by building in large margins but perhaps at some weight penalty.

A known unknown is, for example, the equation of state for plutonium at conditions critical to weapon performance. In this instance, scientists "know what they don't know" and are working to fill in the gaps in their knowledge. That way, they can use their models with confidence to address such issues as the effects of age or manufacturing changes.

An unknown unknown is one in which researchers "don't know they don't know." An example is an anomaly in data from past underground nuclear experiments. Several tests of a weapon gave the same result, but another, whose parameters appeared to be similar, provided an unexpected result. "We don't know why it happened," says Johnson, "and we need to figure it out." High-fidelity experiments, simulations, and data from past underground tests help scientists move the known-unknown and unknown-unknown uncertainties into the known uncertainties category, thus reducing overall uncertainty. Confidence factors would then increase, unless the new results indicated that margins had been overestimated.

An essential component of this process is open and critical evaluation of results. Workshops, peer reviews, joint evaluations with Los Alamos personnel, and senior advisory panels are all venues for exchanging ideas and expertise. Equally important is that the team determining the final confidence factors for a component is not the same team that developed the original watch list for it.

Livermore's second life-extension project for a warhead is under way now. The design team responsible for refurbishing all W80 warheads in the stockpile is using the QMU process to ensure that all credible failure modes have been considered and properly addressed. "The goal is to demonstrate through tests and calculations the set of confidence factors greater than one that are needed for certification of the W80 in 2008," says Johnson.

Into the Future

QMU has proved to be an excellent tool for addressing a range of concerns related to the existing stockpile. In addition, it may eventually be applied to other responsibilities of NNSA's weapons program. Pits, which include the inner shell of plutonium in the primary part of a weapon, change slowly with age as plutonium decays, perhaps reducing the margin for proper performance of the primary. The U.S. does not currently have a pit production facility for replacing existing pits. Is a dedicated production facility needed? And if so, by what date?

These questions cannot be answered definitively yet, but QMU will play a role in formulating the answers.

—Katie Walter

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